



CO₂ Reduction and Upgrading for e-Fuels Consortium

U.S. DEPARTMENT OF ENERGY

**DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review
Carbon Dioxide Utilization**

Markets, Resources, and Environmental and Energy Justice (MarkeRs-EEJ)

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Project Overview

The project will **quantify resource availability and costs** for CO₂ utilization (CO₂U) in sustainable aviation fuel (SAF) production to inform industry, technology communities, and policymakers on location-specific economic and societal impacts.

It will provide insights to guide R&D efforts to achieve BETO's **decarbonization** goals, **SAF cost and production targets**, while meeting DOE's **energy justice** objectives.

We will learn about:

- Future electricity sources, their costs and carbon intensity
- Future CO₂ sources (assuming economic-wide decarbonization) and H₂ sources, their costs and delivery
- CO₂U deployment strategies to achieve better energy justice outcomes



1. Approach: Cross-Sector Modeling Framework

Close collaboration with other projects and Consortium advisory board

TEA-LCA Project (WBS 2.1.0.506 & 507)
Feasibility Study (WBS: 2.1.0.304)

TEA-LCA Analysis

CO₂ Supply Chain Analysis

CO₂U Product and Market Analysis

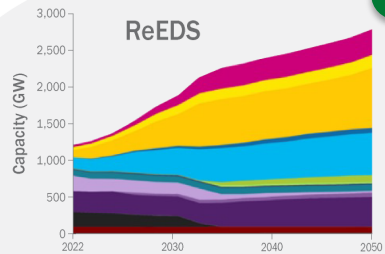
Argonne
NATIONAL LABORATORY

ILCSA (WBS: 4.2.1.31)

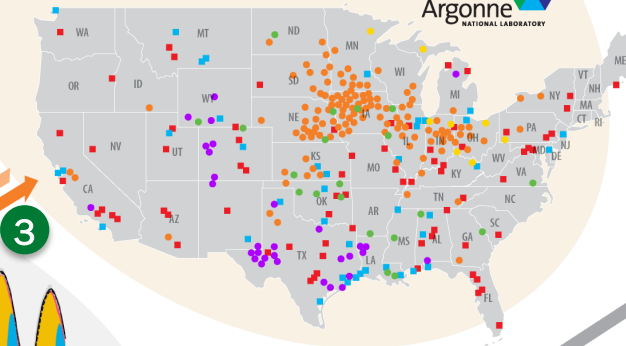
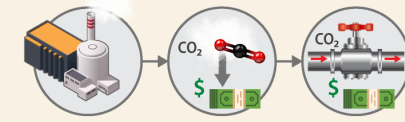
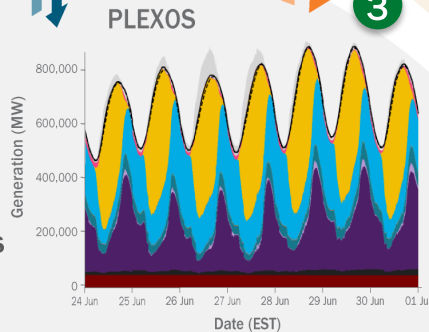
BEIOM

InMAP

Energy and Environment
Justice Analysis



Power Systems
Analysis



- 1 CO₂U production pathways
- 2 CO₂ resources and CO₂U product potential
- 3 Electricity grid information such as emission and electricity cost
- 4 CO₂U resources, deployment scenarios, and locations

1.1a CO₂ Supply Chain and SAF Market

Examine Current and Future CO₂ Sources in 2030 and 2050

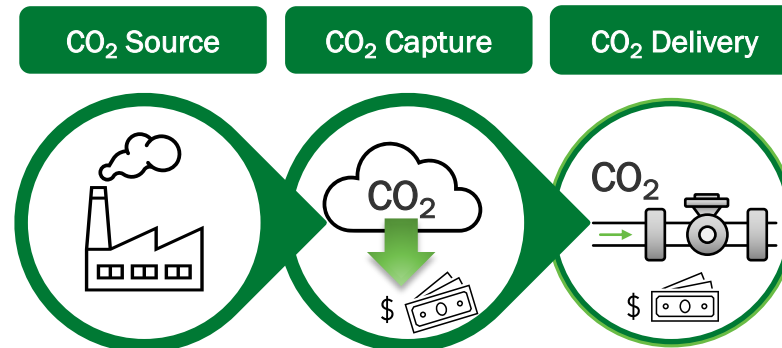
- Estimate industrial high-/mid-purity CO₂ (e.g., bioethanol, ammonia, and natural gas processing).
- Estimate CO₂ using in-house calculation (GREET), EPA GHGRP, and EIA AEO reference case.

Analyze Cost of CO₂ Capture and CO₂ Pipeline Transport

- Capture cost by sources and amounts: NETL reports (Herron et al. 2014, Hughes et al. 2022).
- Calculate transportation cost using ANL CO₂ pipeline transport model



- Available CO₂ for CO₂U products
- Costs of CO₂ capture and transportation



1.1b CO₂ Supply Chain and SAF Market

Sustainable Aviation Fuel

- Current jet fuel market analysis
- Market and consumption outlook (by region)

- Market size of SAF
- Regional CO₂U production capability

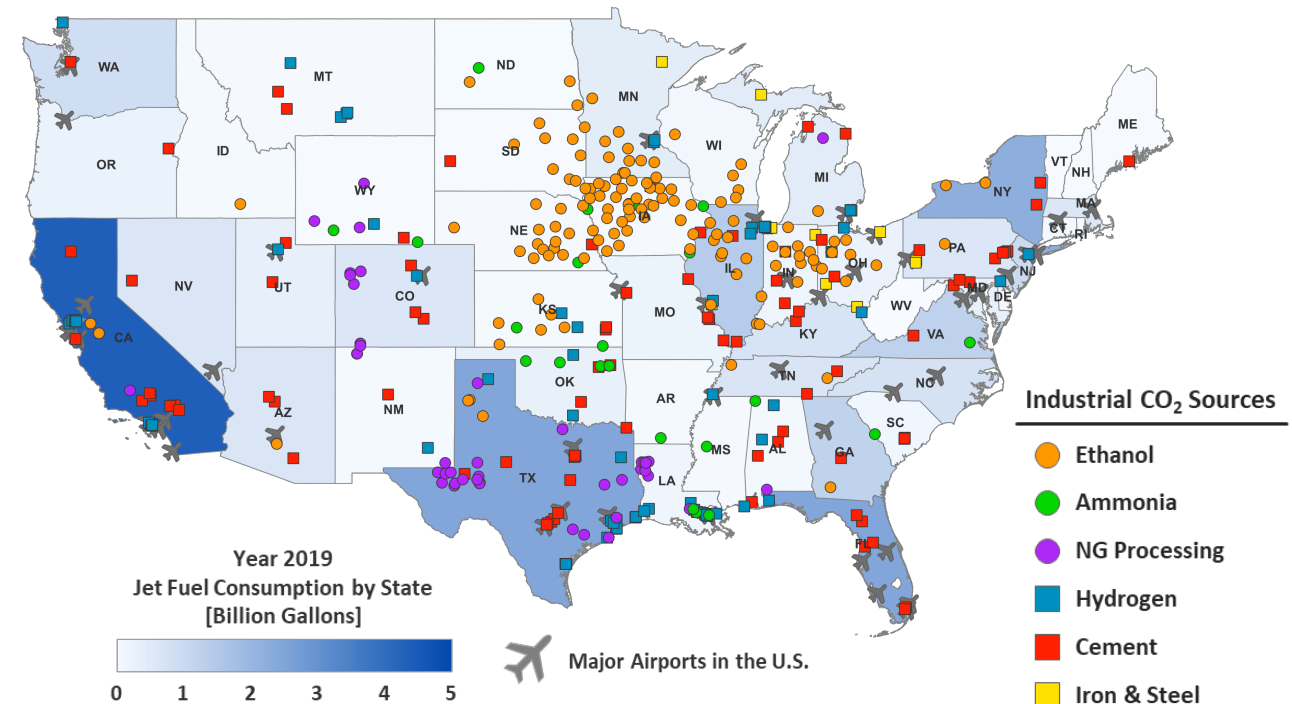
CO₂U Product
Market

Regional CO₂
Source

CO₂U Production
Potential

Estimate SAF Production Potential

- SAF technology selection: TEA-LCA project (WBS 2.1.0.506 & 507)
- Regional SAF production capability with available CO₂ sources
- Regional energy demand for SAF production



1.2. Power System Analysis

- Build CO2U representation in state-of-the-art power system models to provide insights on the changes needed in power system planning and operation to meet future CO2U demands.
- Outputs include hourly electricity costs, generation mix, transmission needs, carbon emissions, etc. for the contiguous United States at high temporal and geographical resolution.

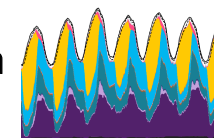


NREL's state-of-the-art power system planning model



- Optimizes deployment of generation, transmission, and end-use demand technologies to meet load and reserves while abiding technical and policy constraints

Commercial power system operation model



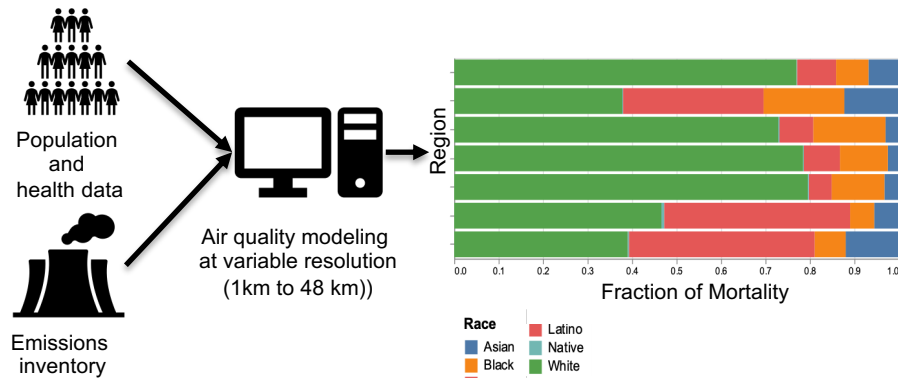
- Performs economic dispatch for ReEDS-built system
- Verifies system is resource-adequate and reliable at hourly level



1.3. Energy and Environmental Justice (EEJ)

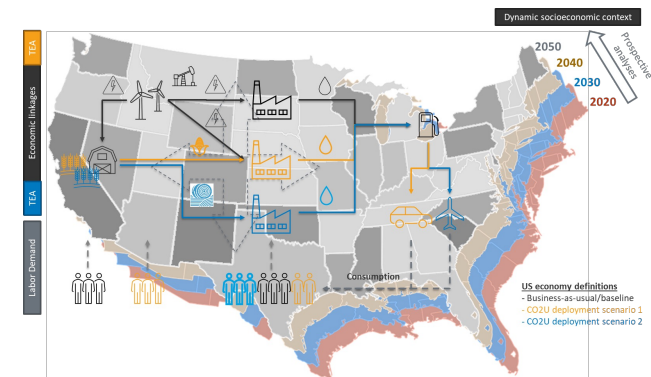
Air Quality and Health Impact Assessment:

- Sector- and location- specific emission estimates
- Health impacts and exposure disparity analysis
- Leverage InMAP (a reduced reduced-complexity air quality model)



Socioeconomic Analysis:

- Total jobs
- Occupations (type, skills, education, and wages)
- Value-added by state and by sector
- Leverage BEIOM (WBS: 4.2.1.31)



1.4 Additional Information on Approach

Risk Mitigation

- Uncertainties in future technology development and demand growth are captured through scenario analysis.
- Actively seek feedback and inputs from other projects, industry representatives, and the advisory board through monthly Consortium meetings.

Go/No-Go

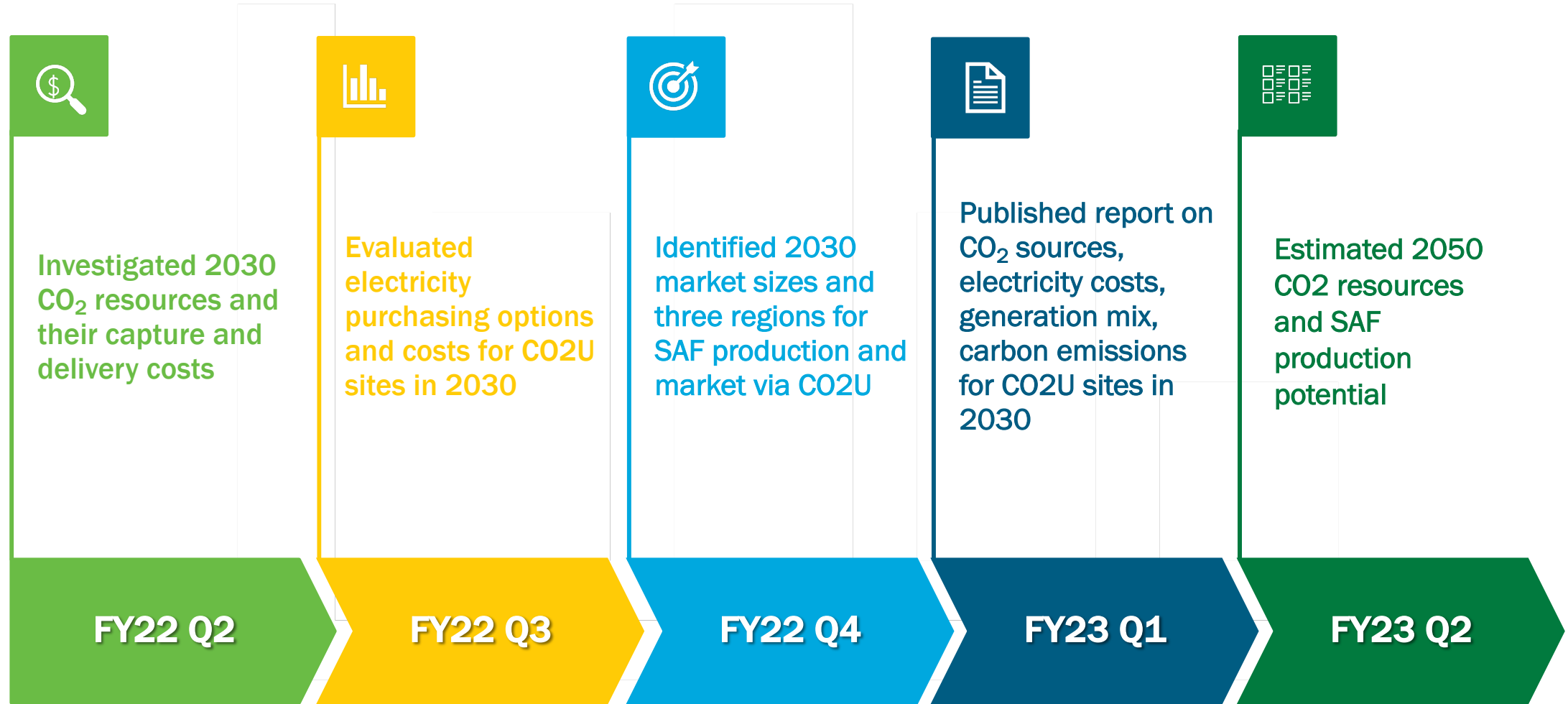
- Sufficient information available for the 2050 analysis: conversion pathways ✓, potential CO₂ sources ✓, electricity cost-to-CO₂U price profiles ✓

Diversity, Equity, and Inclusion

- Research focuses heavily on the energy and environmental justice implications of CO₂U deployment and will examine various equity-related impacts (e.g., air pollution, health, and jobs) to different regions and demographic groups.
- The research results can be used to inform equitable deployment of CO₂U deployment and strategies to improve equity and energy justice outcomes.
- Dissemination of research findings will incorporate diversity, equity, and inclusion. The team will participate in the CO₂ Consortium's outreach efforts and provide accessible, age-appropriate materials (e.g., a video recording) explaining our findings after analyses are completed.
- Project team includes members from diverse racial, ethnic, and educational backgrounds.

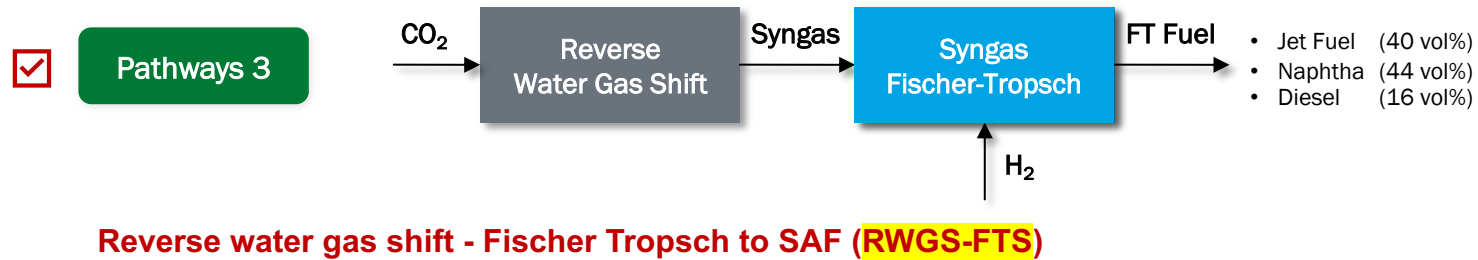
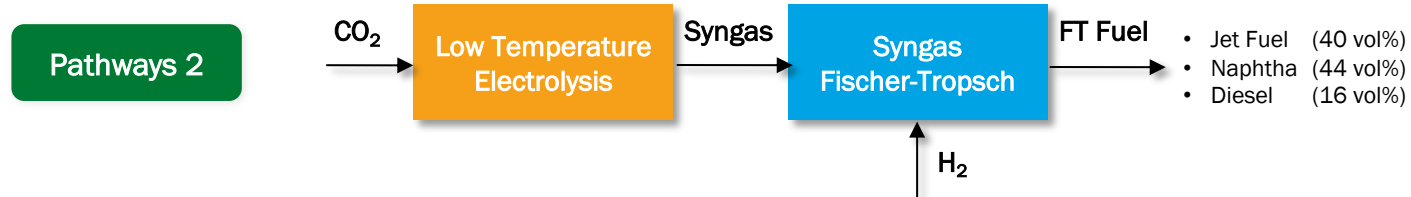
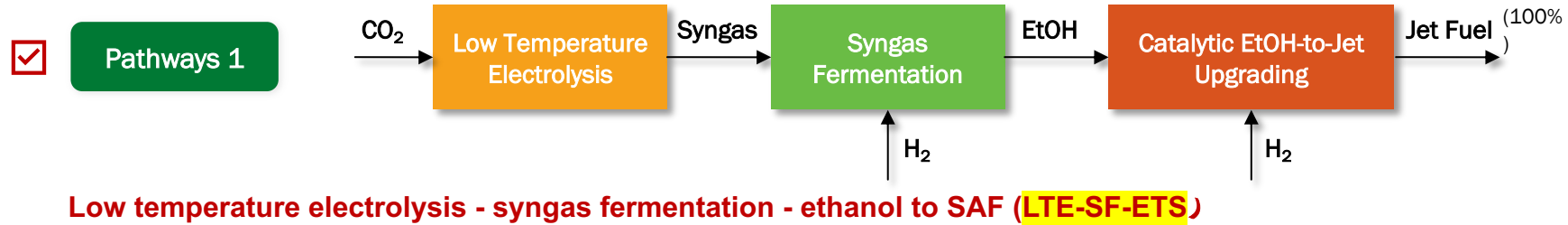


2. Progress and Outcomes



2.0 SAF Technology Pathways*

Focus on Pathways 1 and 3 for CO₂ to jet fuel from the TEA-LCA project



* For SAF pathway details, see next presentation: Economics and Sustainability of CO₂ Utilization Technologies with TEA and LCA (WBS 2.1.0.506 & 507).

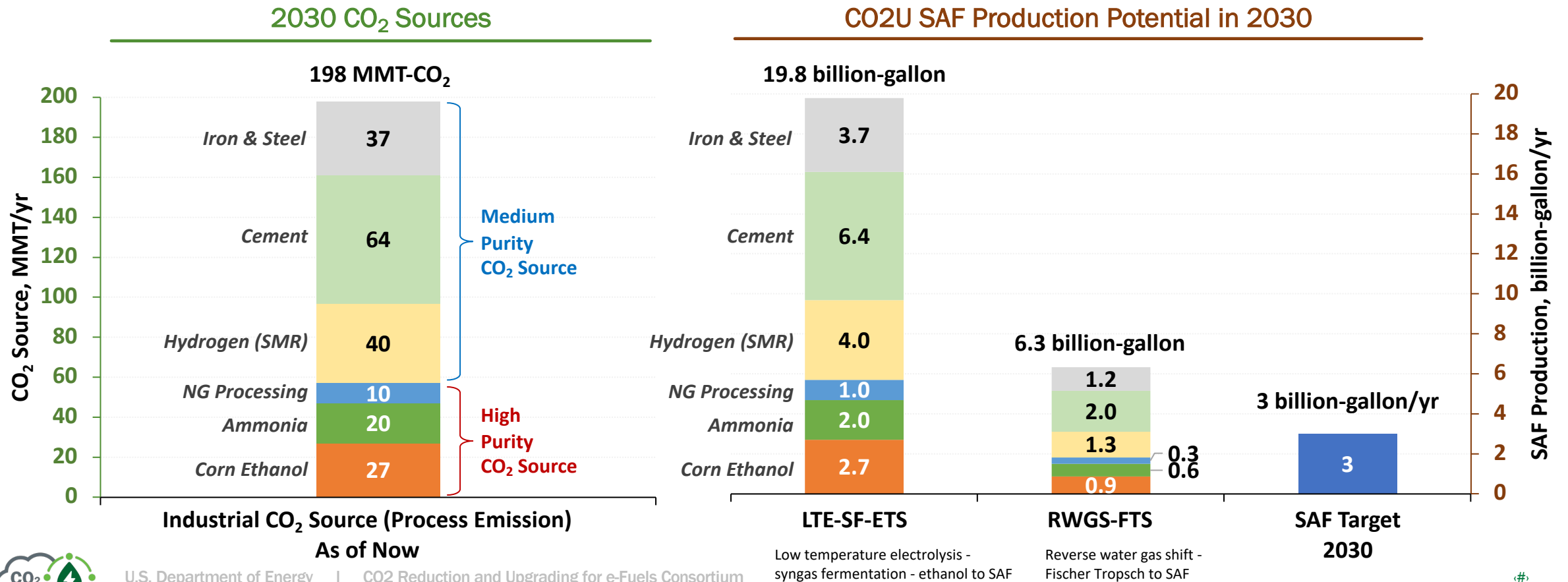


2.1 SAF Production Potential in 2030 (FY22 Q2)

~200 MMT-CO₂ high-/mid- purity CO₂ sources available in 2030 from similar sources to today

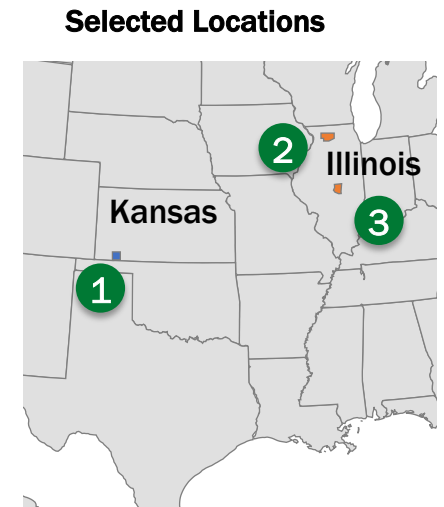
Potential SAF production capability:

- LTE-SF-ETS = ~20 billion-gallon
- RWGS-FTS = ~6 billion-gallon



2.2 Electricity Purchasing Options for Initial Selected Locations (FY22 Q3)

- Published NREL report on electricity costs and carbon implications for CO₂-to-fuels (Li et al. 2022)
- Identified three preliminary locations for proof-of-concept purposes, based on
 - 1) representation of three wholesale power markets (MISO, PJM, and SPP)
 - 2) vicinity to large existing ethanol plants
- Evaluated costs for various electricity purchasing options for each site: retail rate, financial PPA, physical PPA, real-time pricing



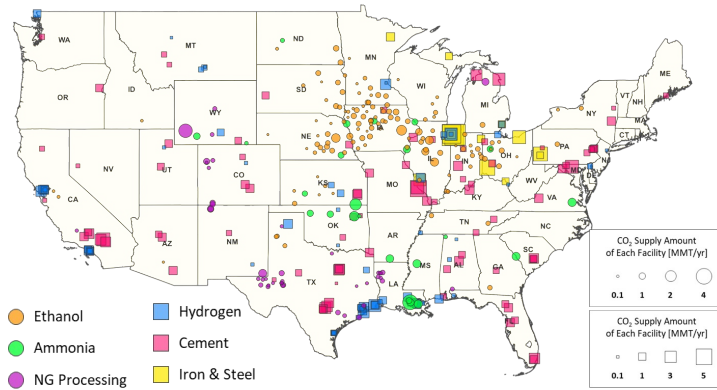
Electricity Purchase Options and Cost (Li et al. 2022)

Plant (Location)	CO ₂ Supply (MMT/yr)	Electricity for CO ₂ U (TWh/yr)	Retail Rate (¢/kWh)	Financial PPA (¢/kWh)
Liberal, Kansas	0.19	1.5	8.3	2.7–3.6
Rochelle, Illinois	0.15	1.2	5.6	3.3–4.4
Decatur, Illinois	0.63	4.8	3.4	3.3–4.4

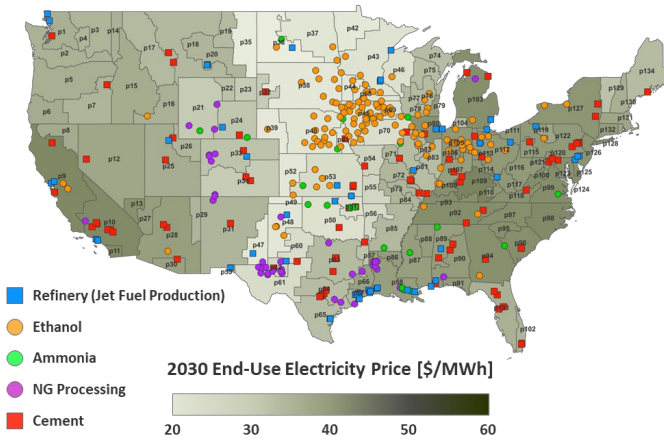


2.3 Analysis of Three Potential SAF Facility Regions in 2030 (FY22 Q4)

Current Industrial CO₂ Source Distribution



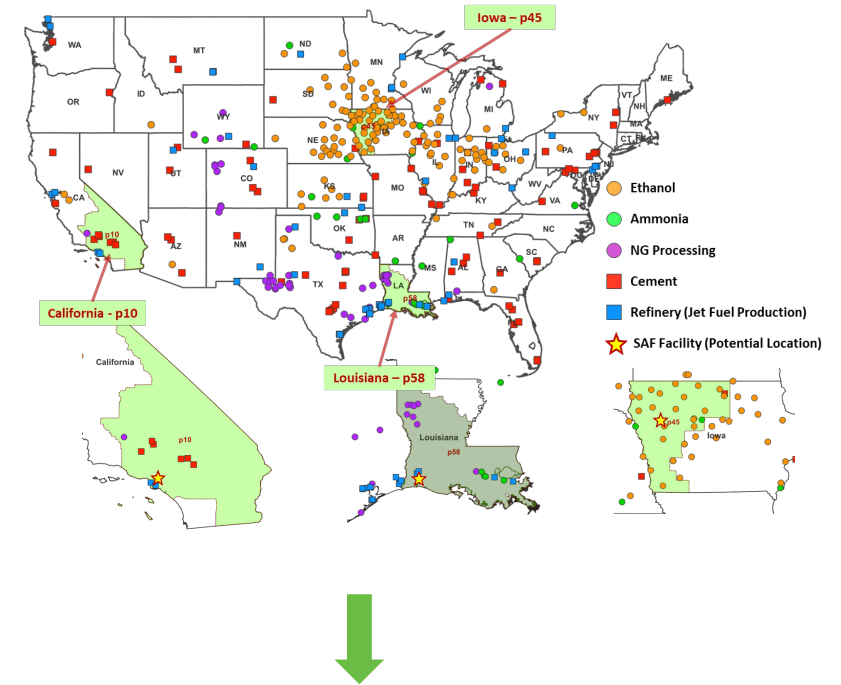
Simulated 2030 Electricity Price (Low Renewable Cost scenario)



Identify regions by

1. Electricity cost in 2030
2. Proximity to CO₂ sources
3. Proximity to jet fuel refineries

Three Identified Regions



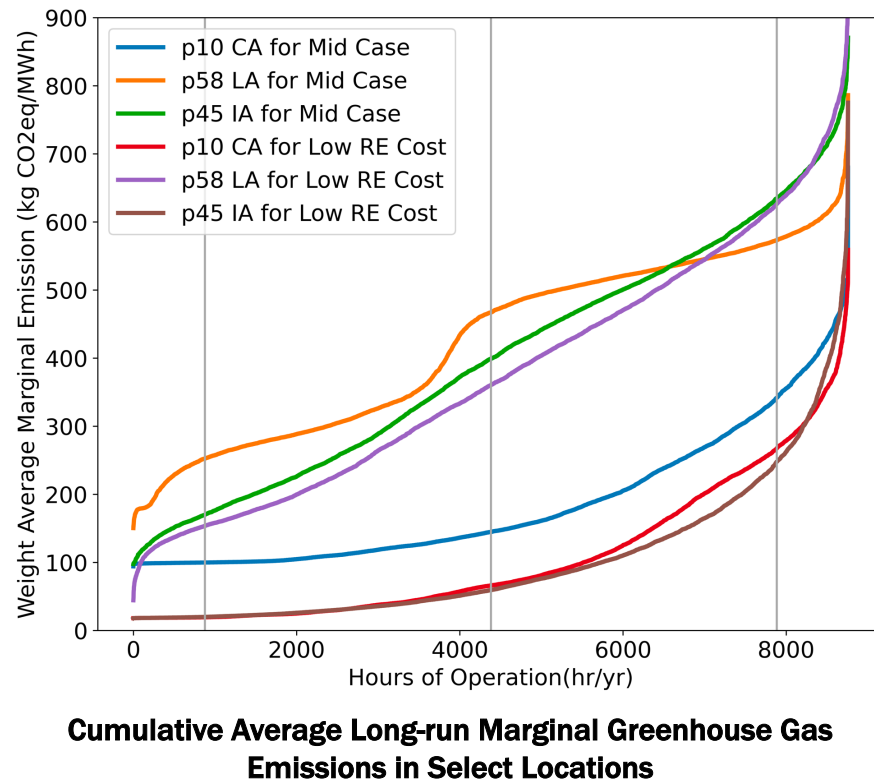
Quantify CO₂ source and electricity demand

- Estimate CO₂ sources from 200-mile radius
- Produce expected SAF production amount and electricity demand (inputs to the FY23 Q1 Milestone)

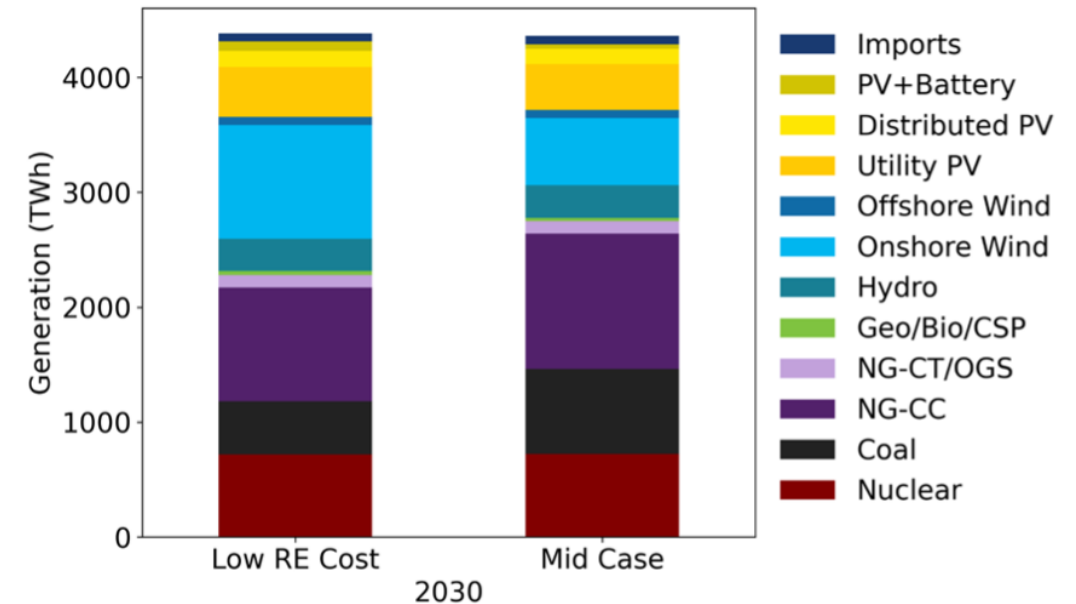


2.4a Generation Mix, Carbon Emissions, and Electricity Purchasing Options for Identified Regions (FY23 Q1)

- Published NREL report (Li et al. 2023): *Near-Term Electricity Requirement and Emission Implications for Sustainable Aviation Fuel Production with CO₂-to-Fuels Technologies*



National Generation Mix in 2030
(adapted from Cole and Carag 2022)



- Assessed CO₂ sources, carbon emissions, and electricity generation mix in three locations and quantified costs for various electricity purchasing options (next slide)



2.4b Generation Mix, Carbon Emissions, and Electricity Purchasing Options for Identified Regions (FY23 Q1)

- PPAs, where available, can often provide cost advantage to other purchasing options.
- Utility tariffs typically include demand charges which can be reduced if the CO2U facility can operate flexibly. A utility may also charge distribution upgrade costs to large new loads that trigger a network upgrade, adding to project costs.

Purchase Options and Electricity Cost Ranges (Li et al. 2023)

Facility Location	Energy Demand (TWh/yr)	SAF Production (million gallons/yr)		Retail Rate (\$/MWh)	Financial PPA (\$/MWh)
		LTE-SF-ETS	RWGS-FTS		
El Segundo, California	5.8	67	22	35	35–48
Sulphur, Louisiana	4.5	52	17	49–51	33–45
Arthur, Iowa	11.2	131	42	71	26–36

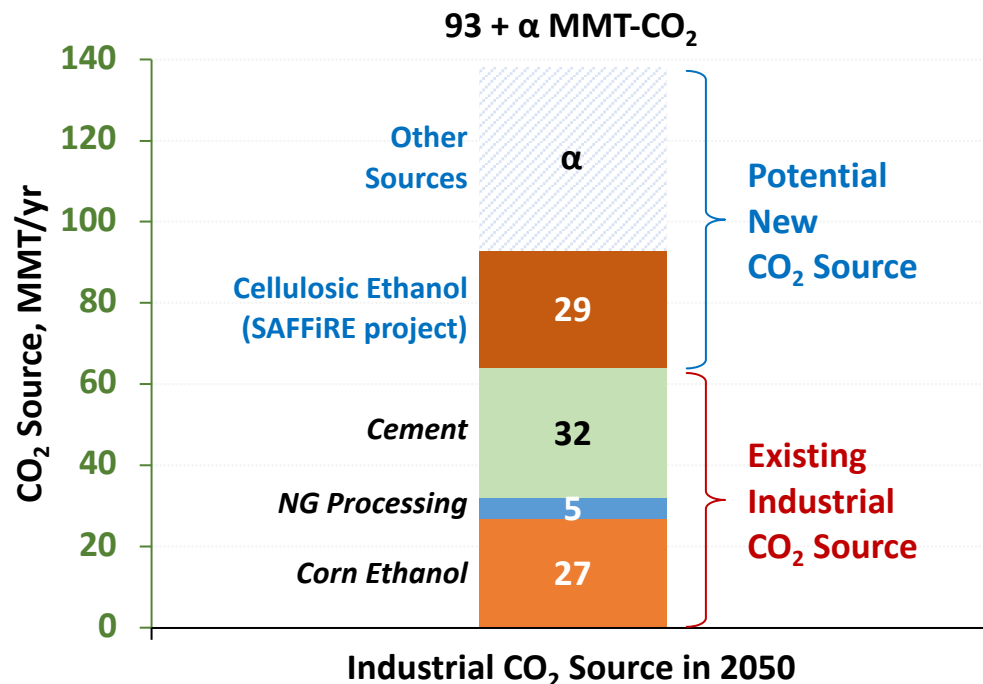


2.5 CO₂ Sources for SAF Production in 2050 (FY23 Q2)

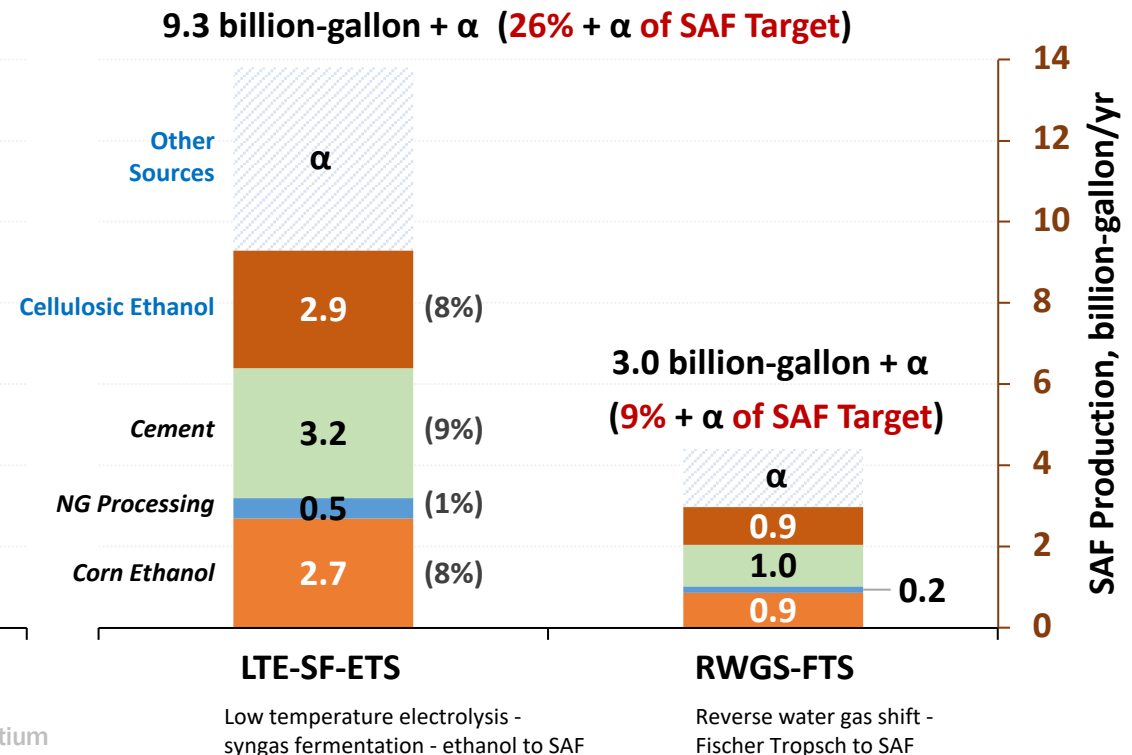
- 64 MMT-CO₂ from selected industrial CO₂ sources
- 29 MMT-CO₂ from new cellulosic ethanol plants
- Other sources (e.g., direct air capture, carbon capture and storage) may be available but the analysis does not depend on them.

- Potential SAF production from the 93 MMT-CO₂
 - LTE-SF-ETS = ~9 billion-gallon (26% of SAF Target)
 - RWGS-FTS = ~3 billion-gallon (9% of SAF Target)

2050 CO₂ Sources



CO₂U SAF Production Potential in 2050



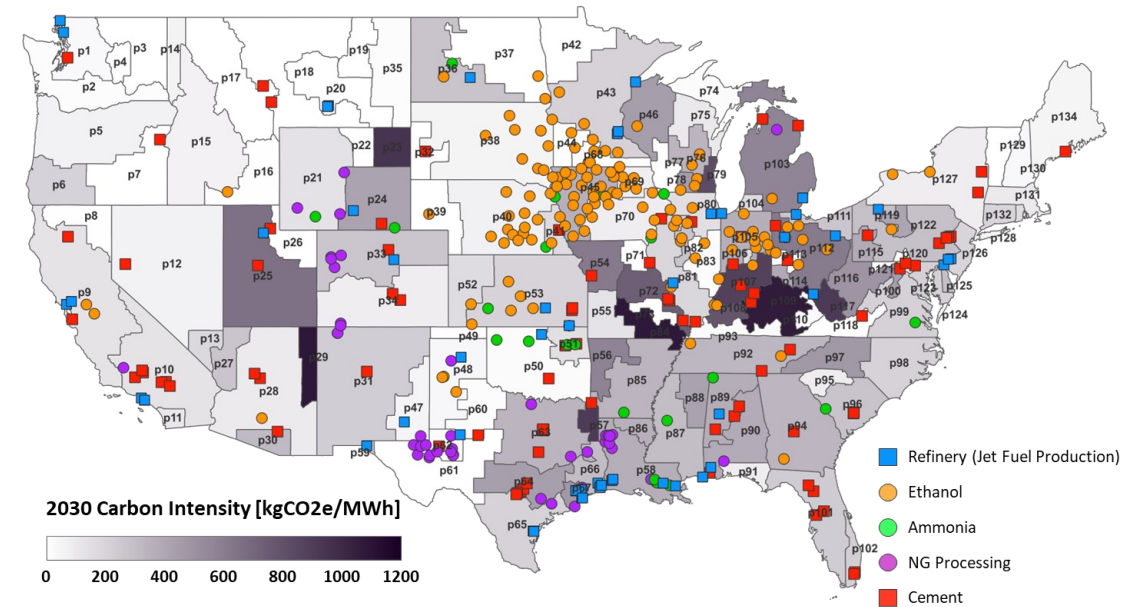
2.6 Future Milestones

Date	Milestone Name/ Description	Type
6/30/2023	Determine whether sufficient 2050 data is available	Go/No-Go ✓
6/30/2023	Joint with WBS#2.1.0.504, conduct grid modeling and CO2U conversation pathways analysis; Estimate delivery and storage cost of CO2 and intermediates	Quarterly Progress Measure
9/30/2023	Develop data sources and approach for emission inventory; Estimate hydrogen delivery and storage costs	Quarterly Progress Measure
9/30/2023	Evaluate the potential of CO2U in 2050, including market locations and sizes, CO2 sources, electricity prices, emissions, and EEJ impacts	Annual Milestone



3.1 Impact for DOE and BETO

- Provide detailed analysis on CO2U's potential contribution towards the 2030 and 2050 SAF production targets.
- Inform DOE's R&D roadmap by providing a holistic analysis of economic, carbon, and energy justice metrics.
- Support BETO's cost target analysis by providing location-specific costs for CO₂, H₂, electricity, resource availability and transportation costs.
- Support BETO decarbonization goals by assessing various sustainability metrics associated with CO2U deployment that utilizes low-carbon electricity
- Provide insights on the impacts of site and technology selection on various EEJ metrics for different demographic groups to inform equitable DOE investment.

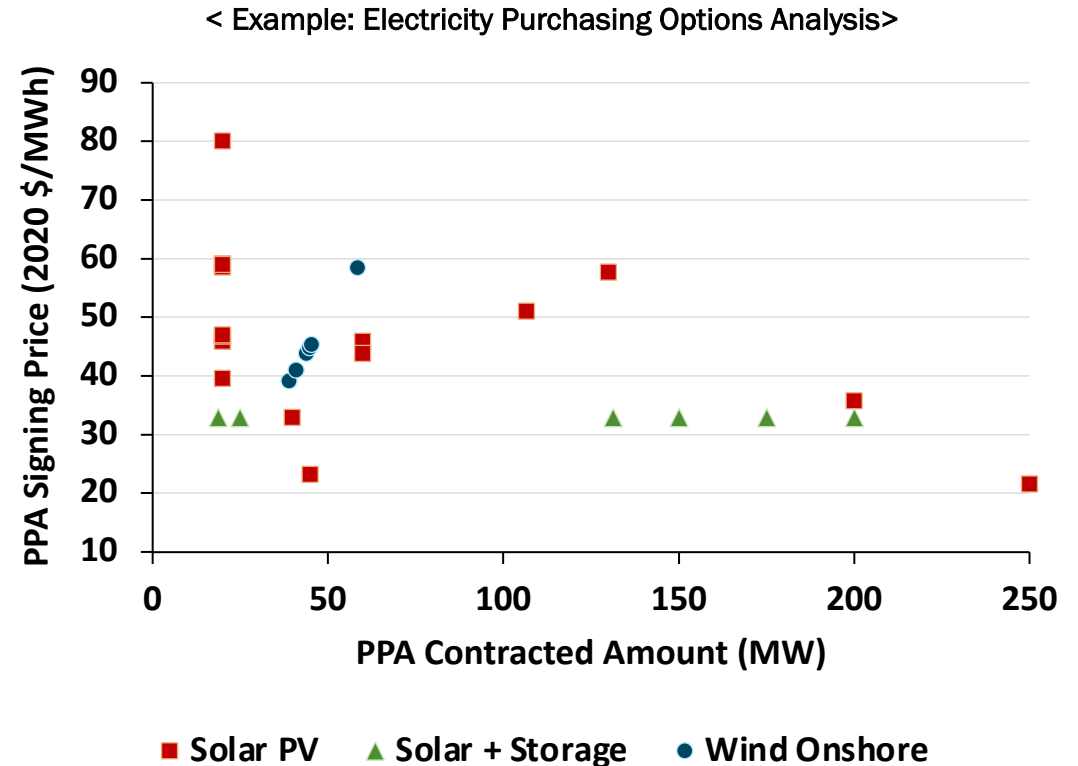


CO₂ Sources and Estimated Power System Carbon Intensities
(kg CO₂e/MWh) in Low Renewable Energy Cost Scenario in 2030
(Li et al. 2023)



3.2 Impact for Industry

- Facilitate project selection and feasibility assessment by providing location-specific costs and availability for CO₂, H₂, delivery infrastructure, and low-carbon electricity.
- Provide insights on the costs, carbon intensities, and risks of various electricity purchasing options for key markets (CA, LA, IA, KS, and IL).
- Inform industry development by providing information on near- and long-term resource availability, SAF markets, electricity cost and carbon intensity projections.
- Provide insights related to corporate sustainability, including potential impacts on air quality, carbon emissions, and energy justice.



Historical PPA Prices and Contract Sizes in California (Li et al. 2023)



3.3 Impact for the Research Community

- Developed a multisector, multidisciplinary modeling framework that evaluates the interactive impacts between the power system and the CO₂U industry as well as their associated environmental and energy justice outcomes.
- Inform R&D efforts and improve sustainability assessment by providing estimates of CO₂ and H₂ sources, delivery costs, electricity costs, and environmental impacts.
- Provide detailed data on CO₂ availability and costs, electricity price, generation mix, and carbon intensity of the CO₂U products for other research efforts, such as the TEA-LCA Project (WBS 2.1.0.506 & 507) and the Feasibility Study (WBS: 2.1.0.304)
- Assessment of environmental and energy justice (EEJ) for the 2050 scenarios, accounting for CO₂U industry-induced changes in the power system, will be provided to the broader community of interests.
- Published two technical reports
- Additional project results will be disseminated through Consortium websites, journal articles, conference talks and/or webinars.



Summary

Today's production and market locations for fuels and chemicals are largely determined by fossil fuel resources and existing infrastructure (e.g., natural gas and petroleum oil).

To achieve DOE's decarbonization and energy justice objectives, at-scale investment in CO₂U technologies needs to be informed by detailed analyses of CO₂ and H₂ resources and costs, non-fossil electricity availability and prices, air emissions, job and GDP impacts, and other factors.

This project informs the development of the CO₂U industry by (1) assessing the resource potential, market potential, and infrastructure requirements for near-term (2030) and long-term (2050) deployment of CO₂U technologies; and (2) evaluating the EEJ implications. The insights can be used across a large portfolio of CO₂U technologies so stakeholders can make decisions according to both economic and societal factors.



Markets, Resources, and EEJ of CO₂-to-Fuels Technologies/2.1.0.504

01/01/2022 – 09/31/2024

	FY22 Costed	Total Award
DOE Funding	\$700,000 (NREL)	\$2,025,000 (NREL); \$600,000 (ANL)

Project Partners

- Economics and Sustainability of CO₂ Utilization Technologies with TEA and LCA (WBS: 2.1.0.506/ 2.1.0.507)
- Feasibility Study of Utilizing Electricity to Produce Intermediates from CO₂ and Biomass (WBS: 2.1.0.304)
- Integrated life cycle sustainability analysis (ILCSA) (WBS: 4.2.1.31)

Project Goal

Quantify location-specific H₂ and CO₂ resources and costs of their delivery and electricity demand; assess CO₂ utilization product market sizes and values.

Evaluate the environmental and energy justice (EEJ) implications of deploying CO₂U technologies in the near term and long term and identify alternative system developments and deployment options required to achieve DOE’s EEJ goals.

End of Project Milestone

Draft report summarizing the potential for a CO₂U industry in 2050, including market locations and sizes, CO₂ sources, electricity availability and prices, and air quality & associated health impacts, and socioeconomic factors.

Funding Mechanism

Annual Operating Plan FY22

List of Abbreviations and Acronyms

AEO	Annual Energy Outlook
ANL	Argonne National Laboratory
BEIOM	Bio-based circular carbon economy Environmentally-extended Input-Output Model
BETO	Bioenergy Technologies Office (DOE)
CO₂	carbon dioxide
CO₂e	carbon dioxide equivalent
CO₂U	carbon dioxide utilization
DOE	U.S. Department of Energy
EEJ	environmental and energy justice
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EtOH	ethanol
FT	Fischer–Tropsch
GHGRP	Greenhouse Gas Reporting Program (U.S. Environmental Protection Agency)
REET (model)	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
H₂	hydrogen
ILCSA	Integrated life cycle sustainability analysis
InMAP	Intervention Model for Air Pollution
kWh	kilowatt-hours

List of Abbreviations and Acronyms

LCA	life cycle assessment
LTE-SF-ETS	Low temperature electrolysis - syngas fermentation - ethanol to SAF
MMT	million metric tons
MWh	megawatt-hour
NETL	National Energy Technology Laboratory
NREL	National Renewable Energy Laboratory
PM _{2.5}	particulate matter, 2.5 microns or less
PPA	power purchase agreement
R&D	research and development
ReEDS	Regional Energy Deployment System Model
RWGS-FTS	Reverse water gas shift - Fischer Tropsch to SAF
SAF	sustainable aviation fuel
TEA	techno-economic assessment
TM	technical monitor
TWh	terawatt-hours

References

Cole, Wesley, J., and Vincent Carag. 2022. *2021 Standard Scenarios Report: A U.S. Electricity Sector Outlook*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A40-80641. <https://doi.org/10.2172/1834042>.

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